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BEARINGS

5 The present invention relates to plain journal bearings, particularly though not exclusively, for internal combustion engines and to so-called overlay coatings deposited upon the running sliding surface of such bearings.

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Overlay coatings on plain journal bearings are well known. Such coatings are used to improve the running characteristics of plain bearings. Generally, overlay coatings are relatively soft metal alloys having a  
15 hardness in the region of about 15Hv; are frequently based on alloys of lead; and, are deposited on another harder bearing alloy at a thickness in the range from about 10 to 30µm. Overlay alloys of the type under consideration are usually applied by electro-deposition  
20 from aqueous plating solutions.

The bearings on which the overlays are deposited are of generally cylindrical or, more commonly, semi-cylindrical form as half-bearing shells which support the crankshaft  
25 journals of internal combustion engines, for example. Such bearings generally comprise a layer of a strong backing material such as steel, for example, on which is bonded a layer of a bearing material frequently chosen from alloys of aluminium or copper. The method of  
30 attaching the layer of bearing alloy to the strong backing may be any that is suitable and may include techniques such as pressure welding of sheets of bearing alloy to the backing; the casting of molten alloy onto the backing; or, the sintering of powders of alloy to the

backing, for example, these methods not being exhaustive. The overlay alloy coating is deposited on the surface of the harder bearing alloy and endows the finished bearing so formed with properties which include conformability  
5 and the ability to embed dirt particles and so prevent scoring of a shaft journal by particles of debris carried in the lubricating oil. Although overlay alloys in their bulk form are relatively weak alloys, they have the ability when applied as a thin layer to another, harder  
10 bearing alloy to increase the fatigue strength of a bearing embodying that harder and intrinsically stronger bearing alloy. This is effected due to the conformability of the overlay alloy by being able to deform slightly to accommodate slight mis-alignments, especially in new  
15 engines during the "running in" phase, and so spread the load more evenly across the bearing surface area.

As noted above, many conventional overlay alloys are based on alloys of lead. Lead is a toxic metal which will  
20 eventually be phased out of use by governmental legislation throughout the world. In order to make the lead-based overlay layer less prone to corrosion in hot engine oils about 10 weight% of tin is frequently added or, alternatively, 7 to 10 wt% of indium. Indium,  
25 however, is relatively very expensive compared with tin and tends to be used for more expensive, higher performance vehicles. However, when tin is used in the overlay alloy and is deposited upon a harder bearing alloy such as copper-lead, for example, a problem exists  
30 in that the tin under engine operating conditions tends to diffuse out of the overlay into the lead of the underlying bearing alloy, as does indium. This is solved by coating the surface of the underlying, harder bearing alloy with a thin diffusion barrier of about 1-3 $\mu$ m of a

- metal such as nickel. However, this is not entirely satisfactory as diffusion still occurs and the overlay still becomes depleted in tin due to the formation of non-equilibrium intermetallic compounds such as  $\text{Ni}_3\text{Sn}$  or
- 5  $\text{Ni}_3\text{Sn}_2$  which are not good bearing materials in the situation where the shaft journal wears through the overlay to the underlying interface comprising these intermetallic compounds.
- 10 With the ever increasing demands placed on bearings by engines having higher specific outputs and operating at higher engine revolutions, there has been a demand for these relatively soft overlay alloys to have improved wear resistance whilst at least maintaining existing
- 15 levels of fatigue, cavitation resistance and corrosion resistance. This demand has resulted in the development of so-called lead-tin-copper overlay alloys an example of which is  $\text{Pb-10Sn-2Cu}$ .
- 20 Thus, it is an object of the present invention to provide an overlay layer which is not toxic and a further object is to provide an overlay which does not form undesirable compounds at an interface with an underlying, harder bearing material. A yet further object is to provide an
- 25 overlay having improved performance over known lead-based overlay alloys.

According to a first aspect of the present invention there is provided a plain bearing having an overlay

30 material layer at a sliding surface of the plain bearing, the plain bearing comprising a layer of a strong backing material, a layer of a first bearing alloy bonded to the strong backing material and a layer of a second bearing alloy comprising said overlay material bonded to said

35 first bearing alloy layer wherein said second bearing

material comprises tin having included in the matrix thereof an organic levelling agent.

5 The tin overlay layer according to the present invention comprises essentially pure tin in that there are no metallic alloying constituents, other than unavoidable impurities, however, the tin is deposited from a bath containing additions of one or more organic materials which have the effect of so-called "levelling" on the  
10 electro-deposited tin layer.

Organic materials which have been tested in bearings of the present invention embodying tin overlays include nonylphenolpolyglycolether and pyrocatechol. The content  
15 of the organic material in the plating bath has an influence on the degree of levelling achieved in the deposited tin layer, the degree of levelling being reflected in the surface roughness of the tin layer.

20 At low levels of organic levelling agent, too low for the full benefit of the present invention to be felt, the surface appearance of the bearing surface is one of a generally crystalline appearance having pools of smooth material distributed over the surface. At a content of  
25 organic levelling agent where the whole surface is smooth, this is the desirable minimum content.

It is believed that the organic levelling agent is incorporated in the matrix of the deposited tin layer as  
30 polymer chains occluded in the matrix structure such as in the form of an organo-metallic tin compound, for example. The polymer chains appear to impart a preferred orientation to the tin atoms during deposition which has been found to give improved slip properties. Improved  
35 slip properties have been evidenced by lower coefficients

of friction in the tin layer compared with ordinary tin deposits without the levelling additions. The surface of the tin overlay of the bearing of the present invention is very smooth giving a lower degree of friction against  
5 a co-operating shaft journal which in turn gives improved compatibility between bearing surface and shaft journal resulting in lower wear rates.

The organic constituent of the tin overlay produces an  
10 increased hardness in the range from about 20 to 30Hv. Pure tin with no organic levelling agent, depending upon its condition, has a hardness of about 8-12Hv. The hardness of the tin overlay can be changed depending upon the content of the organic levelling agent in the plating  
15 bath; the lower the content, the lower the corresponding hardness. The reverse is also true in that as the content of levelling agent increases, so also does the hardness. However, it is possible to have too high a content of organic levelling agent such that the hardness is too  
20 high and high internal stresses are produced in the deposit which can lead to cracking of the tin deposit. It is intended that the overlay of the bearing of the present invention operates in a similar manner to conventional overlays in that the overlay layer is  
25 sufficiently soft to permit particles of dirt circulating in the lubricating oil to become embedded in the overlay so as to prevent such dirt particles from scoring the shaft journal. Whilst the tin overlay of the present invention is harder than pure tin by a factor of X2 to X3  
30 it is still sufficiently soft to provide the required characteristic of dirt embeddability thus, the preferred hardness range is 20 to 30Hv.

The bearing of the present invention may preferably have  
35 an interlayer between the surface of the first bearing

material and the tin overlay to act as a diffusion barrier therebetween. The metal layer may be of a thickness lying in the range from about 0.1 to about 3 $\mu$ m with a thickness of 1 to 2 $\mu$ m being preferred, however, the actual thickness is of comparatively little importance in terms of bearing performance. The metal may be selected from the non-exhaustive group including nickel, cobalt, copper, silver, iron and alloys of these metals, for example. It has been found that under engine operating conditions the tin overlay reacts with the nickel interlayer over time to form the stable equilibrium intermetallic compound, Ni<sub>3</sub>Sn<sub>4</sub>, due to the presence of effectively an excess of tin. As noted above, prior art lead-tin overlays tended to form the unstable, non-equilibrium Ni<sub>3</sub>Sn or Ni<sub>3</sub>Sn<sub>2</sub> compounds which are poor bearing materials and have inferior compatibility with a shaft journal and have been blamed in the past for causing seizure when the overlay has worn through to the interlayer. Ni<sub>3</sub>Sn<sub>4</sub> on the other hand is a very good bearing material and thus, the overlay of the present invention in addition to having superior resistance to wear and cavitation erosion is also less prone to seizure when the overlay is nearing the end of its life. Thus, this unforeseen effect of generating a good bearing material at the interface is seen as a significant advantage of the bearing of the present invention.

As with known overlay layers, the thickness of the overlay of the bearing of the present invention may lie in the range from about 10 to 30 $\mu$ m with 13 to 18 $\mu$ m being preferred.

The deposition conditions for tin overlays according to the present invention may be varied to produce a range of microstructures. For example, analysis of the tin overlay layer by SEM has revealed no discernible grain size; even  
5 at magnifications of X5000 and X10000 no grains can be resolved. However, coatings having grain sizes of up to 3µm may be produced. It is preferred, however, that a smaller grain size is produced as these provide improved bearing properties.

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According to a second aspect of the present invention, there is provided a method for the deposition of an overlay layer onto the surface of a plain bearing, the bearing comprising a strong backing material having a  
15 layer of a first bearing material thereon, said overlay being deposited upon the surface of said first bearing material, the method comprising the steps of: providing a bearing having a surface on which to deposit said overlay; immersing said bearing in a plating solution  
20 having a supply of tin ions and an organic levelling agent in said solution; making said bearing cathodic with respect to an anode in said solution; and depositing an overlay of tin, apart from unavoidable impurities, said tin overlay also having said organic levelling agent  
25 included in a matrix thereof.

30

It is preferred to deposit the tin overlay of the bearing of the present invention by using a so-called "slot jig" wherein the bearing is held with its joint faces against  
a back face of the slot jig with the bore of the bearing facing the slot, the bearing axis and slot being generally parallel to each other. The plating solution, in which the bearing and slot jig are immersed, is also then sparged through the slot towards the bearing bore.

In this way it has been found that relatively high current densities of 2 to 3 A/dm<sup>2</sup> may be employed compared with less than 1 A/dm<sup>2</sup> where the bearing is merely immersed in the plating solution without sparging thereof. Furthermore, the quality of the deposited tin layer is greatly improved compared with that produced without sparging. The use of high current density permitted by the slot jig and sparging technique also reduces plating time from more than 40 minutes to less than 20 minutes.

A typical plating solution producing a tin/organic material overlay on a bearing according to the present invention may have a composition as follows:

15	Sn <sup>++</sup>	32-38 g/l
	SnSO <sub>4</sub>	58-68 g/l
	H <sub>2</sub> SO <sub>4</sub>	185-210 g/l
	Cu	<50mg/l
20	Chloride	<20ppm

Levelling agent additions of nonylphenolpolyglycolether (10-25%) in a methanol carrier (2.5-10%) in the range from 18 to 70 ml/l to the solution specified above have been tested. At the lower end of the range it was found that the degree of levelling and hardness increase was insufficient whilst at the upper end of the range it was found that there was too much inherent stress in the tin deposit and cracking occurred. It was found that concentration in the range from 25 to 55ml/l gave useful increases in overlay performance with little or acceptable deterioration of the fundamental requirements of an overlay alloy in terms of conformability and dirt



embeddability. The content of pyrocatecol was 2.5-10% and amphoteres tensid 2.5% maximum.

It has been found that the leveller content has a  
5 substantially directly proportional effect on hardness of  
the tin deposit. However, a limit of leveller content is  
reached after which the hardness of the tin deposit  
remains constant and then actually begins to fall after  
further increasing the leveller content. Similarly, the  
10 leveller content also has a directly proportional effect  
on surface roughness once the effect of the initial  
substrate roughness and greatly increased surface  
roughness of the initial leveller-free tin deposit have  
been overcome.

15

In order that the present invention may be more fully  
understood, examples will now be described by way of  
illustration only with reference to the accompanying  
figures, of which:

20

Figure 1 shows a cross section through a part of a  
schematic bearing according to the present invention  
showing the constituent layers;

25 Figure 2 shows a top view of a schematic arrangement of a  
plating jig having a bearing being plated with a  
tin/organic material according to the method of the  
present invention;

30 Figure 3 shows a histogram of mean thickness loss of  
overlay vs main journal number in an engine test  
comparing bearings according to the present invention and  
bearings plated with known Pb/In overlays;

Figure 4 shows a histogram of weight loss vs main journal number of overlays of bearings according to the present invention and known Pb/In plated bearings in a 3000hour engine test;

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Figure 5 shows a histogram of volume loss of overlays of bearings according to the present invention and known Pb/In and Pb/Sn/Cu overlays in a hot oil corrosion test;

10 Figure 6 shows a histogram of fatigue strength of bearings according to the present invention having a tin/organic material overlay and known Pb/In and Pb/Sn/Cu overlays;

15 Figure 7 shows a histogram of volume loss of overlays of bearings according to the present invention, Pb/Sn/Cu and Pb/In overlays;

Figure 8 shows a graph of leveller content vs hardness;

20 and

Figure 9 which shows a graph of leveller content vs surface roughness of the deposit on a substrate.

25 Referring now to Figure 1 which shows a cross section of a small portion of a generalised bearing 10 according to the present invention. The bearing comprises: a strong backing material 12 (only a part of the thickness of which is shown); a layer of a first bearing material 14  
30 bonded to the backing 12; an interlayer 16; and, an overlay layer 18 of tin which includes an organic levelling agent combined in the matrix thereof. The backing layer 12 may be steel, for example, but may be any other suitable material such as bronze for example if  
35 corrosion conditions in the application dictated such.

The first bearing material layer 14 may be any that is suitable but will generally be chosen from copper-based alloys or aluminium-based alloys. The interlayer 16 is present to form a diffusion barrier to stop rapid  
5 diffusion of the tin from the overlay 18 into the bearing alloy layer 14 in the case of copper-based alloys 14 and to improve the adhesion of the overlay to the bearing alloy in the case of aluminium-based alloys 14. The interlayer will generally be deposited by electro-  
10 deposition where the overlay is so deposited and may comprise a layer of nickel or other suitable material as described hereinabove. In use, the bearing 10 will be subject to temperatures up to about 160°C. At temperatures of 90°C and above, the tin from the overlay  
15 will react with the interlayer material to form the stable intermetallic compound  $\text{Ni}_3\text{Sn}_4$  in the case of a nickel interlayer. The rate of formation increases as the temperature rises. The  $\text{Ni}_3\text{Sn}_4$  layer grows at the expense of the overlay, however, the  $\text{Ni}_3\text{Sn}_4$  layer is a good  
20 bearing material per se with good compatibility with the co-operating shaft journal (not shown) and thus, does not present a possible seizure threat. The thickness of the interlayer 16 generally lies in the range from 1 to 3µm and the thickness of the overlay 18 generally in the  
25 range from 13 to 18µm.

Figure 2 shows a top plan view of a schematic arrangement  
20 of electro-plating apparatus for depositing an overlay 18 on a bearing 10. The apparatus comprises a jig 22  
30 having two plates 24, 26 spaced either side of a slot 28. The bearing 10 is held against the plates 24, 26 on its joint faces 30. The jig 22 is immersed in a bath (not shown) of plating solution 32 as is a tin anode 34 of generally cylindrical form. The bearing 10 is made

cathodic by a suitable electrical connection (not shown).  
A sparging tube 36 having holes 38 is situated vertically  
in the bath in a fixed relationship to the slot 28.

Plating solution is pumped through the tube 36 so as to  
5 emerge in jet form, as indicated by the arrows 40, which  
are directed towards the bore of the bearing 10 through  
the slot 28. Although not apparent from Figure 2, the jig  
22 is elongate as are the anode 34 and sparging tube 36  
and there is generally a stack of a plurality of bearings  
10 10 being plated simultaneously.

In the tests results which follow, the overlay was  
deposited upon the relevant substrate alloy bearing alloy  
14 and interlayer 16 from a plating bath having the  
15 following composition:

	Sn <sup>++</sup>	32-38 g/l
	SnSO <sub>4</sub>	58-68 g/l
	H <sub>2</sub> SO <sub>4</sub>	185-210 g/l
20	Cu	<50mg/l
	Chloride	<20ppm

Levelling agent additions of nonylphenolpolyglycolether  
(10-25%) in a methanol carrier (2.5-10%) in the range  
25 from 32 to 35 ml/l were added to the above aqueous  
solution.

The interlayer 16 material was in all cases nickel.

30 Figure 3 indicates the results of a 3000 hour test on a  
Volvo (trade name) diesel truck engine. Main bearings 1  
to 4 inclusive were fitted with bearings according to the  
present invention as described above whilst main bearings  
5 to 7 inclusive were fitted with bearings of the same

material and construction but having a conventional overlay of Pb-7In. As may be seen from the histogram of Figure 3, the mean overlay thickness loss for bearings of the present invention was less than 10% that of the conventional overlay.

Figure 4 shows the results of the 3000 hour Volvo engine test of Figure 3 in terms of weight loss. Weight loss of the bearings according to the present invention was significantly less than 100mg each for the four main bearings on journals 1 to 4 whereas the weight loss of the bearings on journals 5 to 7 was around 1000 mg each.

Figure 5 is a histogram showing weight loss of overlays in hot oil (white medicinal oil which is chosen for its particularly corrosive nature) after 1000 hours at 120°C, the loss being measured in mm<sup>3</sup>. The bearing material on which the overlays were deposited has a composition CuSn10 which was cast onto steel. The overlays were tin as in the present invention, Pb-7In and Pb-10Sn-2Cu. As may be seen from Figure 5, the volume loss of overlays on bearings according to the present invention was about 60% that of Pb-10Sn-2Cu and much less than 10% that of the Pb-7In overlay.

Figure 6 is a histogram showing the fatigue strength of bearings having the overlays specified. The bearings according to the present invention were tested in two forms: one having a thickness of 18µm at the upper end of the preferred thickness range; and, the second having a thickness of 14µm at the lower end of the preferred thickness range. The overlay thicknesses of the prior art Pb-10Sn-2Cu and Pb-7In overlays was 15-16µm. As may be seen from Figure 6 the fatigue strength of the bearings

according to the present invention was significantly greater than the prior art bearings.

Further tests were carried out where the tin overlay  
5 having a thickness in the range from 13 to 18 $\mu$ m was deposited on bearing materials 14 of Cu-30Pb-1.5Sn and Cu-10Sn gave fatigue strengths of 90 to 103 MPa.

Figure 7 is a histogram showing wear test results showing  
10 volume loss of overlay on bearings according to the present invention compared with conventional overlays as described hereinabove. The test conditions were:  
temperature 120°; load 8kg; speed 500 rev/min; duration 10 mins; and a constant flow of 10W oil at 600ml/min. As  
15 may be seen from Figure 7 the volume loss of overlays according to the present invention is less than 50% of Pb-10Sn-2Cu and less than 40% that of Pb-7In.

Tests were also carried out on the cavitation resistance  
20 of overlays on bearings according to the present invention. In these tests, the weight loss of the tin overlay of the inventive bearing was 9mg whereas the weight loss of a Pb-7In overlay under identical conditions was 37mg.

25 Figure 8 shows the effect of leveller content in the plating bath on the hardness of the tin deposit. It may be seen that the hardness increases linearly with increasing content of leveller which was the same as that  
30 in the previously described example.

Figure 9 shows the effect of leveller content on surface roughness of the tin deposit. At low leveller contents below about 2 ml/l of leveller, the high roughness is a

consequence of the substrate surface roughness which was an Ra of 0.44 and the roughening effect of the initial, substantially leveller-free tin deposit. Once the effect of the leveller was such that the surface roughness  
5 matched that of the substrate then increasing quantities of leveller were directly proportional to the surface roughness.

Thus, relatively low contents of leveller have a strong  
10 effect in hardening and smoothing out surface roughness of the tin overlays of the present invention.

Thus, it may be seen that the performance of overlays on bearings according to the present invention is greatly  
15 superior to the best conventional overlays deposited by electro-deposition. Where the overlay is deposited upon a lead-free bearing material 14, the bearing of the present invention provides a completely lead-free bearing which complies with future legislation relating to the  
20 elimination of lead from vehicles.